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14. ABSTRACT Objective: This study estimates the prevalence of injured patients requiring prehospital supplemental oxygen based on existing recommendations and determines whether actual use exceeds those recommendations. Patients and Methods: Prehospital oxygen use and continuous peripheral oxygen saturation measurements were prospectively collected on a purposive sample of injured civilians transported to an urban level 1 trauma center by paramedics. Structured chart review determined injury characteristics and outcomes. Supplemental oxygen administration indications were hypoxemia (peripheral oxygen saturation < 90%), hemorrhagic shock (systolic blood pressure < 100 mmHg), or paramedic suspicion of traumatic brain injury. Results: Paramedics enrolled 224/290 screened subjects. Median (range) age was 34 (18-84) years, 48.7% were nonwhite, 75.4% were male, and Injury Severity Score was 5 (1-75). Half (54.5%) were admitted; 36.2% sustained a penetrating injury. None underwent prehospital endotracheal intubation. Hypoxemia occurred in 86 (38.4%), paramedics suspected traumatic brain injury in 22 (9.8%), and 20 (8.9%) were hypotensive. Any indication for supplemental oxygen (107/224 [47.8%, 95% CI 41.3%-54.3%]) and prehospital administration of oxygen (141/224 [62.9%, 95% CI 56.2%-69.2%]) was common. Many (35/141 [24.8%]) received oxygen without indication. Conclusions: On the basis of current guidelines, less than half of adult trauma patients have an indication for prehospital supplemental oxygen, yet it is frequently administered in the absence of clinical indication.					
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Prevalence of Prehospital Hypoxemia and Oxygen Use in Trauma Patients

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ABSTRACT Objective: This study estimates the prevalence of injured patients requiring prehospital supplemental oxygen based on existing recommendations, and determines whether actual use exceeds those recommendations. Patients and Methods: Prehospital oxygen use and continuous peripheral oxygen saturation measurements were prospectively collected on a purposive sample of injured civilians transported to an urban level 1 trauma center by paramedics. Structured chart review determined injury characteristics and outcomes. Supplemental oxygen administration indications were hypoxemia (peripheral oxygen saturation $\leq 90\%$), hemorrhagic shock (systolic blood pressure < 100 mmHg), or paramedic suspicion of traumatic brain injury. Results: Paramedics enrolled 224/290 screened subjects. Median (range) age was 34 (18–84) years, 48.7% were nonwhite, 75.4% were male, and Injury Severity Score was 5 (1–75). Half (54.5%) were admitted; 36.2% sustained a penetrating injury. None underwent prehospital endotracheal intubation. Hypoxemia occurred in 86 (38.4%), paramedics suspected traumatic brain injury in 22 (9.8%), and 20 (8.9%) were hypotensive. Any indication for supplemental oxygen (107/224 [47.8%, 95%CI 41.3%–54.3%]) and prehospital administration of oxygen (141/224 [62.9%, 95%CI 56.2%–69.2%]) was common. Many (35/141 [24.8%]) received oxygen without indication. Conclusions: On the basis of current guidelines, less than half of adult trauma patients have an indication for prehospital supplemental oxygen, yet is frequently administered in the absence of clinical indication.

INTRODUCTION

Although the only true indication for supplemental oxygen is hypoxemia, oxygen is the most commonly administered prehospital medication and many trauma patients receive supplemental oxygen during Emergency Medical Services (EMS) evaluation and transport.¹ Hypoxemia significantly worsens outcomes after severe traumatic brain injury² and supplemental oxygen is often administered to buffer the risk of such secondary injuries, but there is no clear evidence that such treatment affects outcomes. Similarly, when blood is not available for emergent transfusion, high-flow supplemental oxygen is administered in an attempt to increase the amount of dissolved oxygen in serum as an adjunctive therapy in hemorrhagic shock—again without strong supporting evidence that this practice is beneficial.^{2–4} In fact, there is recent contrarian evidence that hyperoxemia results in unimproved or worsened outcomes in many conditions, including TBI, questioning the routine use of supplemental oxygen when hypoxemia is not present.^{2,5–7}

Even in the absence of evidence of clinical benefit, the general dearth of information surrounding the role of supplemental oxygen during initial trauma care has led to the proliferation of nonevidence-based guidelines, including those from the Committee on Trauma Combat Casualty Care, recommending the routine use of oxygen and setting thresholds of 90% to 95% peripheral oxygen saturation (SpO₂) as targets for intervention.^{8–11}

This study aims to estimate the prevalence of injured patients who require prehospital supplemental oxygen based on existing recommendations, and to determine whether actual use exceeds what is recommended.

PATIENTS AND METHODS

Study Design

This was an observational prospective cohort study approved by the institutional review boards of the University of Cincinnati (Ohio) and Wright Patterson Air Force Base (Ohio). Given the minimal risk nature of the study and difficulty obtaining consent in the prehospital setting for many persons in the target population, a modified consent process was implemented. This study was registered with ClinicalTrials.gov (NCT01074983).

Participants and Setting

Traumatically injured persons being transported to the Emergency Department (ED) of the region's only level 1 trauma center by one of six participating ground EMS agencies were eligible. The approximate ED census is 90,000 visits annually, including 3,400 trauma cases. We used purposive

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The preliminary results of this work have been presented in oral format at Advanced Technology Applications for Combat Casualty Care (2011, Fort Lauderdale, Florida), and in poster form at Neurocritical Care (2011, Montreal, Quebec, Canada) and American College of Emergency Physicians (2011, San Francisco, California).

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sampling to choose the six EMS agencies from almost 100 that transport patients to the trauma center based on participation in previous research and to capture varying geographic and demographic populations (urban, suburban, rural), injury patterns (blunt vs. penetrating), and prehospital times. The EMS systems are municipal fire-department based, and prehospital care is delivered by paramedics.

Participants were identified during initial prehospital care or transport. Adults (18 years old or greater) with any mechanism of injury or injury severity were included. Prehospital personnel identified and included participants by applying a study-specific pulse oximeter (Nonin PalmSat 2500; Nonin Medical, Plymouth, Minnesota); this oximeter is virtually identical to the model previously deployed by the EMS agencies, with the additional capability of recording heart rate, SpO₂, and signal quality to an internal memory every 4 seconds. Participants without oximetry data were excluded.

Procedures

At the beginning of the study and routinely during the study, EMS personnel were trained to treat patients according to regional EMS protocols. There was no dedicated supplemental oxygen provision protocol; however, existing protocols suggest supplemental oxygen application for medical patients with SpO₂ < 95%, trauma patients with signs of hemorrhagic shock (systolic blood pressure < 100 mmHg), or suspicion of TBI.¹² The protocols do not prescribe the flow of oxygen to be given.

On patient arrival at the ED, clinical study assistants (CSAs) interviewed the EMS providers regarding use of supplemental oxygen, indications of oxygen need, and other details of prehospital care. CSAs continuously staff the ED, and subjects were enrolled regardless of time of day or day of week. In addition, the heart rate and oxygen saturation measures that were recorded by the study-specific pulse oximeter were downloaded. After initial patient stabilization and evaluation, treating physicians provided information outlining the mechanism and severity of injuries. At this time, informed consent was obtained from all participants or their legally authorized representative, as required by U.S. Federal Regulation 10 USC 980, which applies to research funded by the Department of Defense. Participants in whom consent was not possible (i.e., death in ED without next of kin available) or who refused consent were excluded and all data were destroyed.

For consenting participants, charts were reviewed for treatment course, summary of injuries, disposition, and Injury Severity Score (ISS) at least 30 days after discharge. Rigorous chart review methodology was used, including the use of a standardized abstraction form with data definitions, trained abstractors, and dual data entry with adjudication of data queries.¹³ Thirty-day mortality was determined by both Social Security Death Index and hospital records review performed at least 6 months after enrolment.

Primary Outcomes

The primary outcome for this study was whether or not a participant received supplemental oxygen or had an indication for oxygen in the prehospital setting. Indications for oxygen were defined as any SpO₂ ≤ 90% (in accordance with Tactical Combat Casualty Care guidelines),¹⁰ hemorrhagic shock (systolic blood pressure < 100 mmHg), advanced airway management (i.e., bag-valve-mask ventilation and endotracheal intubation), or paramedic clinical suspicion for TBI as documented in the EMS run report or revealed during the CSA's interview of the EMS providers. Use of oxygen was determined by the CSA's direct observation or discussion with the EMS crew.

Sample Size

This was an observational study to determine the prevalence of prehospital hypoxemia and supplemental oxygen usage in trauma patients, and subjects were enrolled over a fixed time interval. The target enrollment was 100–350 subjects knowing that the 95% confidence intervals (CIs) of the proportion of patients requiring supplemental oxygen will extend ±10% if the measured proportion is 50% and the sample size is 100, or ±5% if the sample size is 350. If the measured proportion approaches zero or one, the CI will become tighter.

Data Management and Analysis

Study data were collected and managed using REDCap (Research Electronic Data Capture) electronic data capture tools (Vanderbilt University, Nashville, Tennessee).¹⁴

Case report forms underwent double data entry; queries were resolved by focused medical record review. Pulse oximetry data were managed using nVision (Nonin Medical, Plymouth, Minnesota) and Microsoft Excel (Microsoft, Redmond, Washington). Missing and poor signal quality data, flagged by the device, were corrected using linear interpolation based on the closest leading and trailing values (Matlab; MathWorks, Natick, Massachusetts).

Data analysis was primarily descriptive. The prevalence of indications for oxygen was estimated as a proportion with 95% CIs calculated using the score method. Relative risks (RRs) with 95% CIs were used to explore factors associated with a need for oxygen. Statistical analyses used SPSS version 20.0 (IBM, Armonk, New York).

RESULTS

Between February and December 2010, the six participating EMS agencies transported 290 injured patients to the trauma center with the study pulse oximeter applied; 224/290 (77.2%) met full enrolment criteria. Exclusion criteria included no SpO₂ data recorded to the device ($n = 21$), consent refusal ($n = 27$) or withdrawal ($n = 2$), death before consent was possible ($n = 5$), ED discharge before consent ($n = 7$), and failure to meet inclusion criteria ($n = 4$). The enrolled subjects are described in Table I.

TABLE I. Patient Characteristics Stratified by Indication for Supplemental Oxygen

	Total		O ₂ Indication (n = 107)		No O ₂ Indication (n = 117)		RR	95% CI	
								Lower	Upper
Age	34	18–82	34	18–82	34	18–78			
Race									
White	109	48.70%	57	53.30%	52	44.40%	1.2	0.92	1.57
Nonwhite	115	51.30%	50	46.70%	65	55.60%			
Male	169	75.40%	85	79.40%	84	71.80%	1.11	0.95	1.28
Penetrating Injury	81	36.20%	35	32.70%	46	39.30%	0.83	0.59	1.18
EMS: Initial GCS < 15	48	21.40%	36	33.60%	12	10.30%	3.23	1.78	5.86
ISS	5	1–75	9	1–75	4	1–29			
AIS Chest Score									
Present	60	26.80%	36	33.60%	24	20.50%	1.64	1.05	2.56
0 No Injury	164	73.20%	71	66.40%	93	79.50%			
1 Minor	15	6.70%	6	5.60%	9	7.70%			
2 Moderate	11	4.90%	6	5.60%	5	4.30%			
3 Serious	30	13.40%	21	19.60%	9	7.70%			
4 Severe	1	0.40%	1	0.90%	0	0.00%			
5 Critical	3	1.30%	2	1.90%	1	0.90%			
6 Nonsurvivable	0	0.00%	0	0.00%	0	0.00%			
Admitted	122	54.50%	77	72.00%	45	38.50%			
Dead at 30 Days	3	1.30%	3	2.80%	0	0.00%			
O ₂ Given by EMS	141	62.90%	86	80.40%	55	47.00%			
Suspected TBI	22	9.80%	22	20.60%	0	0.00%			
Hemorrhagic Shock	20	9.00%	20	18.70%	0	0.00%			
O ₂ Given in First 24 Hours of Admission	86	70.50%	60	77.90%	26	57.80%			
Prehospital SpO ₂ ≤ 90%	86	38.40%	86	80.40%	0	0.00%			
Prehospital SpO ₂ 91%–95%	99	44.20%	17	15.90%	82	70.10%			
Prehospital SpO ₂ > 95%	39	17.40%	4	3.70%	35	29.90%			

Data are presented as median and range or frequency and percentage. AIS, abbreviated injury score; O₂, oxygen. Relative risks with 95% CI are presented for selected variables. The difference in medians for age is 0 (95% CI –8.10 to 8.10). Difference in medians for ISS is 5 (95% CI 2.53–7.47).

The median age was 34 (range 18–84) years, 48.7% were nonwhite, and 75.4% were male. More than half (54.5%) were admitted to the hospital. The median ISS was 5 (range 1–75); 36.2% sustained a penetrating injury. No subject underwent endotracheal intubation in the prehospital setting; 7 (3.1%) underwent intubation in the ED. Mortality was low, with two in-hospital deaths and one additional death within 30 days of discharge.

Overall, 141/224 (62.9%) received oxygen and 107/224 (47.8%) had a documented indication for supplemental oxygen (Table II). Prehospital hypoxemia (SpO₂ ≤ 90%) was observed in 86/224 (38.4%), paramedics suspected TBI in 22 (9.8%), and 20 (8.9%) subjects were hypotensive. Although paramedics

suspected TBI in 22 cases, initial Glasgow Coma Scores (GCS) were <15 in 48 subjects: seven severe (GCS 3–8), 19 moderate (GCS 9–12), and 22 mild (GCS 13–14). Of the 141 subjects who received oxygen, 35 (24.8%) had no documented indication. Conversely, oxygen was not supplied to one subject with a documented indication.

In subjects who experienced hypoxemia, the total duration was highly variable, ranging from 4 seconds to 45 minutes. The median duration of recorded hypoxemia was 72 seconds. Subjects with an indication for supplemental oxygen had higher ISS scores (9 vs. 4, difference in medians 5 [95% CI 2.5–7.5]), an increased likelihood of initial EMS GCS score <15 (RR 3.2, 95% CI 1.8–5.9), and an increased likelihood of chest ISS score >0 (RR 1.6, 95% CI 1.1–2.6) (Table I). There was no evidence that age, race, gender, or penetrating mechanism of injury influenced indication for supplemental oxygen.

DISCUSSION

We found that a majority of civilian trauma patients received supplemental oxygen, but only a minority actually showed a guideline-based indication for supplemental oxygen before ED arrival. Hypoxemia was the most common indication for supplemental oxygen, and hypotension and paramedic suspicion for TBI occurred in almost 10% of subjects each.

TABLE II. Frequency of Indications for Supplemental Oxygen Administration

	N	%	95% CI	
			Lower	Upper
Pulse Oximeter Oxygen Saturation ≤90% (Hypoxemia)	86	38.4	32.2	44.9
TBI	22	9.8	6.5	14.3
Hemorrhagic Shock	20	9.0	5.7	13.2
Intubated	0	0.0	0	1.1
Documented Oxygen Indication (Any of the Above)	107	47.8	41.3	54.3

This observed prevalence is high enough to maintain the availability of supplemental oxygen in the prehospital setting, but there is significant room for improvement in providing this treatment for only those patients with hypoxemia or suspected hemorrhagic shock or TBI.

We chose a threshold of 90% to define hypoxemia as this is an accepted floor value for intervention and because it is consistent with published guidelines.^{9,10} Unfortunately, guideline-based indications rely on largely arbitrary and poorly supported numerical definitions of hypoxemic thresholds, and treatments tied to such values may not offer physiologic benefit. However, empiric provision of supplemental oxygen to trauma patients may not be beneficial.⁷ Conversely, providing too much supplemental oxygen may even be detrimental. There is growing evidence that hyperoxemia may be harmful in some medical conditions, such as stroke, acute myocardial infarction, extreme prematurity, chronic obstructive pulmonary disease, and after resuscitation from cardiac arrest.^{15–20} Extrapolating such observations to the general trauma patient is difficult, but it is certainly plausible that routine oxygen administration is not always beneficial.

There are unintended consequences of the existing nonevidence-based guidelines that generally lead to overuse of supplemental oxygen. Moreover, although application of supplemental oxygen is straightforward for civilian EMS, providing any oxygen at all is challenging in austere, hostile, or resource-depleted settings. In military operations, oxygen cylinders have a significant cube-weight factor; when full, cylinders may pose an explosive or fire risk, and when discarded, could be repurposed by the enemy. Chemical oxygen generators are limited by the flow-rate and volume of oxygen that can be produced, and the exothermic reactions represent a risk of thermal injury. Knowledge of the actual prevalence of oxygen need is essential for planning and care-delivery in such environments.²¹

Although we found that many trauma victims have at least 1 indication for supplemental oxygen before hospital arrival based on current guidelines, the need is far from universal, and it is still not clear how high a flow rate is required to maintain adequate oxygen saturation. Additional study is needed to better define the minimum amount of oxygen required to prevent or reverse hypoxemia. Furthermore, studies assessing the clinical impact of supplemental oxygen use in patients with TBI or hemorrhagic shock without hypoxemia are needed to better inform the development of evidence-based recommendations for oxygen provision in the setting of trauma.

Limitations

Our data show that supplemental oxygen is not universally indicated for trauma patients before hospital arrival, but our results must be interpreted with respect to limitations inherent in the study design. Although all injured patients were eligible, few subjects in the final cohort were severely injured.

Informed consent is required by U.S. Federal Regulation 10 USC 980, which applies to research funded by the Department of Defense, and 5 subjects who died in the ED were excluded because of the inability to obtain informed consent. This will likely have resulted in an underestimate of true prevalence of indications for oxygen because our data suggest that injury severity is associated with oxygen need. However, this is balanced by the exclusion of seven subjects who were directly discharged from the ED before consent could be obtained and who were likely minimally injured. An additional 21 subjects were unable to be enrolled because of technical failure of the study oximeter to record data or corruption of the resulting data file; these occurrences were scattered among the devices and participating departments. The small number of poor outcomes also limits the possibility of generating insight into the impact of prehospital hypoxemia on mortality.

There is the possibility that some hypoxemic subjects received therapeutic supplemental oxygen before measurement of oxygen saturation, resulting in an underestimate of the prevalence of hypoxemia. However, although 141 (62.9%) subjects received prehospital oxygen, only 86 (38.4%) subjects were given supplemental oxygen in the first 24 hours of hospitalization, and only 60 (26.8%) had a documented prehospital indication for oxygen. In addition, analysis was performed based on prehospital suspicion of TBI and prehospital hypotension, and not on actual diagnosis of intracranial trauma or hemorrhagic shock; misclassification of these indications for supplemental oxygen could affect our observed results in either direction.

Our local EMS protocols are conservative.¹² Drug-assisted endotracheal intubation is not allowed in the protocols, and short-scene times for trauma patients are strongly encouraged; these factors likely contribute to the observation that no subject underwent field intubation.

CONCLUSIONS

On the basis of current guidelines, less than half of adult trauma patients have an indication for prehospital supplemental oxygen administration, and supplemental oxygen is frequently administered even in absence of clinical indications. Indiscriminate use of supplemental oxygen should be especially avoided when supplies are constrained.

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